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THE POTENTIAL USE OF ROBOTICS IN THE CANADIAN AEROSPACE INDUSTRY

by

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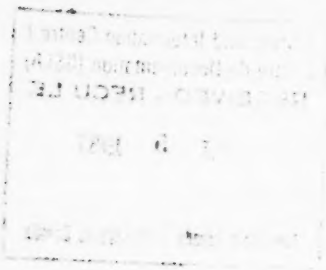

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17. Abstract

An investigation was undertaken to study the potential use of robotics in the Canadian aerospace industry. For the purpose of this study, the Canadair plant was taken as a typical airframe manufacturing operation. Fifteen areas in manufacturing were investigated. These included machine loading, deburring, welding, composites, sealing and sheet metal operations. Four applications were selected for detailed analysis: painting, routing, drilling and water-jet operations. The study reveals that the most effective applications are drilling, routing and water-jet cutting, because of the large number of drilled holes required for fasteners and because most of the parts require some form of routing to shape either before or after assembly. Finally, steps required for a demonstration phase are described.

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17. Résumé

Ce rapport rend compte de l'étude sur l'utilisation potentielle de la robotique dans l'industrie aérospatiale canadienne, Canadair ayant été considérée à cet égard comme l'avionnerie type. Quinze secteurs de fabrication ont été soumis à l'étude, notamment le chargement, l'ébavurage, le soudage, les matériaux composites, l'étanchéisation et la tôlerie. Les quatre applications choisies pour une analyse détaillée ont été le peinturage, le toupillage, le perçage et le travail par jet d'eau. L'étude a révélé que les applications les plus efficaces étaient le perçage, le toupillage et le coupage par jet d'eau en raison du grand nombre de trous à percer et de la fréquence des travaux de toupillage soit avant, soit après l'assemblage des pièces. Enfin, le rapport termine par la description de la phase suivante, qui est celle de la démonstration.

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SUMMARY

INTRODUCTION

Higher cost of production, lower average productivity and loss of skills are some of the factors driving the manufacturing industry towards automation. Robotics is one method of automating the manufacturing process; consequently the use of robots in the manufacturing industry is growing rapidly. The introduction of robotics in aerospace manufacture, although initially slow, is gathering momentum. To be competitive, the Canadian aerospace sector must embrace this new technology.

This report examines the potential areas of robotics application in aerospace manufacture. For the purpose of this study, Canadair is taken as a typical airframe manufacturing operation.

The study was undertaken for the Transportation Development Centre with a view towards establishing a Canadian industry presence in the field of robotics.

Hard automation, similar to that employed in the automobile industry, is very difficult to introduce in the aerospace industry owing to the nature of aerospace production. Large production runs are the exception in this business where small batch size, complex parts and frequent changes in component configuration are the norms. High capital investment and changeover costs have made the aerospace industry relatively labor-intensive until recently.

The advent of the new generation of robots has given impetus to the introduction of automation in aerospace production. This is because of their programmability, flexibility and relatively low equipment costs. Furthermore, the increased degree of sophistication and the improved reliability of the latest generation of robots open up more areas for application.

ANALYSIS

Initially a survey was made of the potential application areas. These were analysed and four were selected for a detailed study. The following application areas were involved in the initial study.

- Machine Loading/Material Handling
- Deburring
- Welding
- Chemical Processing/Heat Treatment
- Sheet Metal Operations
- Electrical Harness Making
- Composites
- Assembly
- Drivematic Operations
- Extrusion Finishing
- Sealing

To improve operations in these areas, it was found that there was a need for:

° The introduction of other technologies such at GT (Group Technology) prior to robotics, or

° the purchase of modern capital equipment instead of robots, or

° the introduction of more sophisticted robots, or

° further development in a robotics laboratory.

The following application areas were selected for detailed study:

° Painting
° Routing
° Drilling
° Water-jet operations

Although there are benefits in using a robot for painting, the characteristics of aerospace production and the difficulty in programming the present generation of robots preclude the use of robots unless an unusual production rate justifies it.

Drilling and routing/water-jet cutting are extensively used processes in aerospace manufacturing. Most aerospace components require some form of cutting or trimming, before, during or after assembly. Moreover, as thousands of mechanical fasteners used in aircraft assembly require the drilling of holes, the potential exists for the use of robots.

It was found that almost all of the current robotic applications in the aerospace industry in North America are in the drilling and routing/trimming area.

The use of composites in aerospace is growing at an accelerated rate. The water-jet is a relatively new and effective method of cutting composites and is seen as a potential area for robotic application.

CONCLUSION

The use of Robotics in aerospace manufacturing is no longer a dream but an industrial reality with increasing application. Although, the aerospace industry has lagged behind other industries in robotic application, the new generation of robots will overcome this relative inertia. The increasing use of robotics will influence design which, in turn, will generate a further need for advancement.

This is a new technology that has to be acquired. There is no readily available pool of people with robotics experience. Hence the skills have to be learned, experience gained and the technology base developed, if the Canadian aerospace industry is to remain competitive internationally.

It will require time, effort and money. Most of the U.S. aerospace companies engaged in robotics have the support of government agencies. These agencies support projects for near-term applications, as well as for R & D work, in order to establish a technology base for the future. Robotics in Canadian aerospace will also require government support and funding.

The areas for robotic application recommended for demonstration in phase II are drilling and routing/water-jet cutting. The cost of phase II is assessed at $300,000 (1983 dollars) spread over two years.

RÉSUMÉ

INTRODUCTION

Les coûts plus élevés de production, la productivité moyenne plus faible et la diminutiondes compétences sont au nombre des facteurs qui mènent l'industrie vers l'automatisation. La robotique est une méthode qui permet d'automatiser les processus de fabrication; aussi l'utilisation des robots est de plus en plus répandue dans l'industrie. L'introduction de la robotique dans l'industrie aérospatiale, bien que lente au départ, prend désormais de l'ampleur. L'industrie aérospatiale canadienne doit donc adopter cette nouvelle technologie si elle veut demeurer concurrentielle.

Ce rapport analyse les secteurs potentiels d'application de la robotique dans l'industrie aeronautique. A cette fin, la compagnie Canadair a été choisie comme exemple type d'avionnerie.

L'étude a été entreprise par le Centre de développement des transports afin de faire connaître l'industrie canadienne dans le secteur de la robotique.

L'automatisation à gande échelle, comme dans le cas de l'industrie automobile, est très difficile à instaurer dans l'industrie aérospatiale en raison de la nature même du type de production. Les grandes chaînes de production sont exceptionnelles dans ce domane; C'est plutôt la fabrication en petite quantité, les pièces complexes et les modifications fréquentes des composants qui constituent généralement la règle. Les investissements de capitaux très élevés et les coûts de rééquipement ont fait de l'industrie aérospatiale un secteur relativement élévé en main-d'oeuvre, du moins jusqu'à ces dernières années.

La nouvelle génération de robots a donné le coup d'envoi à l'introduction de l'automatisation en production aérospatiale. Cela tient au fait qu'ils sont programmables, polyvalents et relativement peu coûteux. De plus, le degré élevé de perfectionnement et la plus grande fiabilité de cette dernière génération permettent de les utiliser dans un plus grand nombre d'application.

ANALYSE

On a d'abord étudié les secteurs d'application potentielle. Après analyse, quatre de ces secteurs ont fait l'object d'une étude plus approfondie. L'étude initiale portait sur les secteurs suivants:

° Chargement/manutention du matériel
° Ébavurage
° Soudage
° Traitement chimique/thermique
° Metal en feuille
° Fabrication de faisceaux de câblage
° Matériaux composites

° Assemblage
° Travail à la riveteuse "Drivematic"
° Finition par extrusion
° Étanchéisation

Pour améliorer les opérations dans ces secteurs, l'étude a fait ressortir les nécessités suivantes:

° Introduction d'autres techniques comme le TG (technolgie de groupe) avant la robotique, ou

° achat d'équipement moderne essentiel plutôt que des robots, ou

° introduction de robots plus spécialisés, ou

° poursuite des développements dans un laboratoire de robotique.

Les secteurs d'application suivants ont fait l'objet d'une étude plus approfondie:

° Peinturage
° Toupillage
° Perçage
° Coupage au jet d'eau.

Même s'il est avantageux d'utiliser des robots pour le peinturage des pièces d'avionnerie, les caractéristiques de production et les difficultés inhérentes à la programmation de la génération actuelle de robots empêchent leur utilisation, à moins qu'un rythme inhabituel de production ne le justifie.

Le perçage, le toupillage et le coupage par jet d'eau sont les opérations les plus courantes dans l'industrie aérospatiale. La plupart des pièces d'avionnerie nécessitent une certaine forme de coupage et d'ébarbage, avant, pendant ou après l'assemblage. De plus, étant donné que les milliers de fixations mécaniques requises pour l'assemblage d'un aéronef nécessitent le perçage de trous, la robotique pourrait certainement être utilisée dans ce secteur.

L'étude a permis d'établir que le perçage, le toupillage et l'ébarbage constituent la quasi-totalité des opérations robotisées dans l'industrie aérospatiale en Amérique de nord.

L'emploi de matériaux composites dans cette industrie s'accroit à un rythme accéléré. Le travail par jet d'eau est une méthode relativement nouvelle et efficace de coupage des matériaux composites et est perçue comme un secteur potentiel d'utilisaion de la robotique.

CONCLUSION

L'utilisation de la robotique dans l'industrie aérospatiale n'est plus un rêve, mais une réalité industrielle dont les applications ne cessent de croître. Même si cette industrie a accusé un certain retard par rapport à d'autres industries en matière d'applications

en robotique, la nouvelle génération de robots permettra de vaincre cette inertie relative. L'utilisation croissante de la robotique influera sur la conception et entraînera un plus grand besoin de perfectionnement.

Nous nous devons de maîtriser cette nouvelle technolgie, mais nous manquons de spécialistes sur place possédant de l'expérience en robotique. Il nous faudra pourtant acquérir les compétences et l'expérience nécessaires, et élaborer des bases technologiques si nous voulons que l'industrie aérospatiale canadienne demeure concurrentielle sur la plan international.

Pour atteindre cet objectif, il faut du temps et de l'argent. La plupart des compagnies aérospatiales américaines qui font appel à la robotique sont appuyées par des organismes gouvernementaux. Ces derniers encouragent les projets d'application à court terme de même que la recherche et le développement afin d'établir une base technologique pour l'avenir. La robotique dans l'industrie aérospatiale canadienne nécessitera également des appuis et du financement.

Les secteurs d'application en robotique recommandés pour la démonstration au cours de la phase II sont le perçage, le toupillage et le coupage par jet d'eau. Le coût de la phase II, évalué à 300 000 $ (dollar de 1983), sera reparti sur deux ans.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. METHODOLOGY 1

3. IN-DEPTH ANALYSIS 2

3.1 Painting 2

3.1.1 General 2
3.1.2 Requirements 2
3.1.3 Benefits 3
3.1.4 Robots on the Market 4
3.1.5 Applications in Aerospace 4

3.2 Routing 5

3.2.1 General 5
3.2.2 Use of Templates 5
3.2.3 Aerospace Applications 6

3.3 Drilling 6

3.3.1 General 6
3.3.2 Use of Templates 7
3.3.3 Aerospace Applications 7

3.4 Water-Jet Operations 8

3.4.1 General 8
3.4.2 Advantages 8
3.4.3 Aerospace Use 8

4. OTHER APPLICATIONS 9

4.1 Machine Loading/Material Handling 9
4.2 Deburring 10
4.3 Welding 11
4.4 Chemical Processing/Heat Treatment 12
4.5 Sheet Metal Operations 12
4.6 Electrical Harness Making 13
4.7 Composites Manufacturing 14
4.8 Assembly 15
4.9 Drivmatic Operations 16
4.10 Extrusion Finishing 17
4.11 Sealing 17
4.12 Misc. Application 18

5. DISCUSSION 18

6. CONCLUSIONS 21

7. RECOMMENDATIONS 22

1. INTRODUCTION

"Automate, emigrate or evaporate" has become the most often used phrase in the manufacturing industry. It may sound simple and cute, but it remains a truism. Many of the basic concepts or methods used in the manufacturing industry have changed or are changing due to automation. The advent of the computer has played a major role in automation and made an even greater impact on manufacturing. Robotics is just another facet of this technological revolution which will change the nature of manufacturing.

Automation, as we know it in the automobile industry, is difficult to introduce in the aerospace industry. This is because of the nature of aerospace production. Small batch size, complex part configuration and frequent changes are some typical characteristics which rule out hard automation. However, flexible programmable automation is a viable alternative in the pursuit of improved manufacturing methods and productivity which is essential to staying competitive.

Robotics is only a small part of the new technological revolution. CADAM (Computer Aided Design And Manufacturing), DNC/CNC (Direct Numerical Control/Computer Numerical Control) and CIM (Computer Integrated Manufacturing) are the other aspects of it. Unless we become aware of it and use it to advantage, our fate will be to revert to that of "hewers of wood and drawers of water".

Most of the larger and medium size aerospace companies are actively involved in developing the use of robots in manufacturing. More and more application areas are being considered and are being investigated. For the Canadian aerospace industry to compete internationally, it must embrace these new technologies, or become one of the casualties of this new industrial revolution.

2. METHODOLOGY

The objective of this study is to indicate the areas in the aerospace manufacturing environment suitable for robotic application and to recommend the robotics in the Canadian Aerospace Industry.

Initially a broad survey was made of potential applications for robotics in Canadair. Application areas were analysed and four were selected for more detailed study. These were painting, drilling, routing and water-jet operations. Information on robotics applications in the manufacturing industry, and particularly the aerospace industry, was obtained from magazine articles, technical papers and visits to other aerospace manufacturers. Information on robots available on the market was obtained from suppliers and manufacturers.

3. IN-DEPTH ANALYSIS

Following an initial study of all the potential areas for robotic application, four were selected for an in-depth study. These were painting, drilling, routing and water-jet cutting. Some of the criteria for the selection of these applications are repetitive operations, dangerous operation/environment, labour intensive operation and long term benifits. It was found that almost all the aerospace companies involved in robotics were considering or had implemented the robotization of these processes in some production applications. These are the prime areas for robotic application, given the state-of-the art of robotic technology. The analyses of various aspects of these applications are given, as follows:

3.1 Painting

3.1.1 General

In the past, spray painting was done by hand, using air-atomizing spray guns. Over the last 30 years new methods of painting have been developed, such as air-less spraying, electrostatic spraying and powder coating. Painting is a dirty and dangerous process which creates an extremely unhealthy environment for the human operator. The most important aspects of concern in the painting process is the effect of paint mist on human health and safety and the attendant fire hazard.

Modern science and technology may never solve the problem of providing a paint material that a sprayer can work in and breathe safely, or discover a new finishing process, but the industry can take the man out of the spray painting process. The immediate answer to this health problem is - the Robot.

3.1.2 Requirements of Painting Process

Paint is applied to any product to protect it from its working environment and to enhance the appearance of the product. The requirements of the painting process in general are as follows:

- The paint must completely cover the surface to be painted.
- The thickness of the paint must be uniform. A good quality finish has no peeling or sagging due to uneven thickness over a wide surface.
- The paint must have a certain minimum thickness.

- There must be a minimum waste of paint.
- The painting process must not impair the health and safety of the spray painters.

- In cold climates, heating of the air in the paint booth requires considerable amounts of energy.
- The air must be continuously refreshed to reduce the amount of paint mist and/or solvent in the air that the spray painter inhales.

3.1.3 Benefits of Robots in Painting

3.1.3.1 Health and Safety:

Spray painting presents a major health and safety hazard on the shop floor. It is suspected that certain pigments are carcinogenic. Inhalation of the paint mist and/or solvent is the major concern. The use of robots in painting will improve the health and safety of shop personnel, by removing humans from the hazardous environment of the paint shop.

3.1.3.2 Energy:

Conventional painting process requires a large amount of air which must be clean, fresh and comfortable for the sprayers. This requires expenditures of large amounts of energy. The paint booths are designed in such a way that the sprayer is protected against fumes and paint mist by the use of forced air circulation, washers and scrubbers. A robot would not need such a protective environment. Therefore, with robots the energy requirements will be reduced significantly.

3.1.3.3 Quality:

One must bear in mind that, the painted appearance of the product indicates the level of quality associated with the product. The efficiency of a human operator drops as the shift progresses. A robot will perform as it is programmed to do all the time. A robot will not get tired and will not require coffee or washroom breaks. Consistency in quality can be achieved with the use of robots for painting, furthermore, a robot can precisely follow part contours and spray the part with better-than-human consistency and precision.

3.1.3.4 Overspray:

A human spray painter has a tendency to spray beyond the edge of a component. He may vary the distance of the nozzle from the spraying surface or dwell when he goes around intricate contours. This causes overspray. The consistancy and uniformity of the operation of a robot aids in achieving a uniform coat of paint and reduce overspray with potential savings of upto 10% in paint costs.

3.1.3.5 Costs:

One of the major costs of the painting process is the cost of equipment to improve the environment, such as special spray booths, forced air circulation system, scrubbers, etc. These costs will largely be avoided in a new robotic paint installation. The use of robots in an existing paint installation will reduce the cost of energy spent and paint used and will save direct labour costs due to its more consistent and tireless operation.

3.1.4 Robots on the Market

Painting is a unique application area in which certain manufacturers have specialised. These manufacturers have developed robots, specifically for painting applications. The manufacturers and the robot models they produce are:

1) DeVilbiss-Trallfa TR-3500
   This is the most extensively used painting robot. Price $78,400 (U.S.)
2) Nordson NRS II — Price $75,000 (U.S.)
3) Nordson NRS 40 — Price $99,000 (U.S.)
4) Thermwood Paint-Miser — Price $45,000 (U.S.)
5) Binks Model 88-800 — Price $90,000 (U.S.)

These are all 6 axes, continuous path servo-controller robots. All are Hydraulically powered and air or air/water cooled and can be programmed by the lead/walk through method. Their accuracy varies from 0.5 to 4 mm and the weight carrying capacity varies from 4.5 Kg to 13.6 Kg.

3.1.5 Applications In Aerospace

The use of the painting robots in the aerospace industry, unlike the automotive industry, has not really caught on. The intrinsic characteristics of aerospace production such as, large numbers of unique parts and small batch sizes, make the justification of a painting robot difficult. Furthermore, almost all painting robots are programmed by the lead through method. This does not make the justification any easier, because, during programming, the robot is unavailable for production and as the part count grows larger, more time is taken for programming.

To simplify this, two companies have programmed the robot to paint the tray which carries the parts. Lockheed-Georgia and Boeing use a DeVilbiss-Trallfa robot to paint small detail components which are carried on a tray, slung from a monorail conveyor. The robots are programmed to paint a fixed area. Boeing use a round tray, which is horizontal and carries the parts. Lockheed use a rack to hold the parts vertically and the robot paints a rectangular area.

Fairchild Republic Co. of New York use a Trallfa Model 3003S robot for painting. The Fairchild application is different because the robot is used to paint large complex structures, such as the nose, mid and aft sections of the A-10 attack aircraft. This application is unique because the robot is mobile and the robot is brought to the work, unlike other applications where the robot paints parts on a conveyor line which brings work to the robot.

Another DeVilbiss TR-3500 robot will be used to strip and paint aircraft and missile components at Ogden Air Logistics Center, Hill AFB, Utah. The rate of production will be about 40,000 per year. It is estimated that the use of robot will reduce the use of stripper by 75% and paint by 30%.

Other aerospace companies which have robotic applications in Painting are McDonnell Douglas-Tulsa division, General Dynamics-Convair division and Vought Corporation of Fort Worth.

3.2 Routing

3.2.1 General

Routing is an important and extensively used process in aerospace manufacturing, especially in sheet metal fabrication. Routing is a continuous path process, where the tool has to make contact with the part/workpiece and applies the cutting force on it by moving on a predetermined line.

Because of the relatively large forces involved, the tool Holder needs to be extremely stiff. The robots currently available on the market lack the required stiffness and have built-in compliance at the end-of-arm. Therefore additional aid is required in the use of robot for routing. Generally templates are used with robots for routing contours.

Furthermore, the accuracy of the current generation of robots is limited, although the use of templates does reduce the amount of accuracy and stiffness demanded of the robot.

When the tool touches the workpiece, the cutting action creates large forces. The current generation of robots have considerably more compliance than machine tools and the cutting/reaction forces together with the compliance can easily create sizable positional errors. None of the current robots can compete with the specialized sheet metal fabricating machines currently on the market.

3.2.2 Use of Templates

Templates for contouring application using robots, have to constrain the movement of the cutter in only one direction, the direction normal to the contour. There are a number of way to achieve this.

One method is to program the tool path parallel to, but inside the required contour of the template (considering an external contour). As the tool moves along the path during the cutting operation, the error between the actual tool position and programmed tool position is sensed by the control system. The control system tries to force the tool into the template to reduce the error, and maintains contact with the template. The force developed between the tool and the template is dependant upon the programmed error and the gain of servos in the control system. The gain must be low enough to prevent the manipulator from damaging the template or the workpiece. In the case of a high gain servo system, the end-effector must have a compliant mounting to absorb the excessive force.

Another method would be to sense the forces acting on the cutting tool and use the signals generated to control the motion of the tool. This is a more complex method and requires interfacing of the end-effector, sensors and the control system.

3.2.3 Aerospace Applications

Robots are being used to rout the periphery of sheet metal and composite panels combined with drilling of attachment holes. General Dynamics of Fort Worth have developed work cells to drill and edge rout interchangeable and replaceable access panels in their F-16 production line.

The cell consists of a Cincinnati Milacron T3 robot together with a rotating part positioner. While the robot works on a part loaded on one side of the part positioner, the operator can load another part on the opposite side of the part positioner. When the part is finished, the positioner can be rotated to present a new part for the robot to work on.

The Interchangeable and Replaceable panels require an accuracy of 0.003/0.005 in. Because of the robot accuracy problem (the current generation of robots have an accuracy of 0.025/0.030 in) hard tooling has to be used.

McDonnell Douglas have a similar workcell to rout composite panels on their production line. An Asea S-1 robot is used to trim composite parts. A reduction of 50% in working time is achieved.

Boeing are developing a robotic cell to trim interior panels and another one for routing to shape honeycomb cores used in various bonded assemblies.

3.3 Drilling

3.3.1 General

Thousands of components are needed in the construction of an aircraft. There are various methods/processes used to assemble these components into sub-assemblies and assemblies, e.g. welding, bonding, rivetting, etc. The method used most extensively is that of mechanical fastening using, rivets, bolts or Hi-Loks.

There are many thousands of fasteners used in the assembly of an aircraft all requiring the drilling of holes consequently drilling is the most frequently used process in the aircraft industry.

Generally the tolerances on drilled holes in sheet metal assemblies depend on the size of holes and the type of fastener. The tolerances on the size of the hole can be from 0.002 in. to 0.005 in. The general positional tolerance of a hole is plus or minus 0.015 in. But in certain cases, such as interchangeable components, the tolerance is much closer. However, the important attribute as regards the positioning of a hole is the edge distance. The minimum allowable edge distance is 1.5 times the diameter of the hole.

3.3.2 Use of Templates

Because the current generation of robots are not accurate enough (the accuracy being in the range of plus or minus 0.050/0.060 in) templates have to be used for drilling applications. Furthermore, the accuracy varies depending upon in which part of the work envelope the drilling operation is being performed. The accuracy deteriorates as the robot is operated towards the edge of the work envelope.

To overcome this, the end effector can be designed such that it compensates for the inaccuracies of the robot. This can be achieved by using elastomeric mountings between the robot and the end effector. The drill needs to be oriented normal to the surface of the workpiece. The template ensures this, or the end effector can be designed with sensors/actuators to do this. Thus smart tooling can be used with a not-so-smart robot.

Another method would be to use special bushes on the template with conical holes and the drill holder with a conical guide spigot. But this method may require modifications to existing tooling with consequent additional cost.

3.3.3 Aerospace Applications

General Dynamics, Fort Worth is the largest user of robots in aerospace manufacture. Most of the applications developed by General Dynamics are for drilling.

The end effector consists of an extension cage, which senses and aligns with the bush in the template. The cage is mounted through elastomeric pads to the robot arm, because compliance has to be built into the end effector due to the inaccuracies and non-rigidity of the robots. The drill is mounted inside the extension case, which feeds the drill into the work. Thus the robot is used only for positioning, the drill feeding is done by the end effector. All the sensors and the robot is controlled by a cell computer.

General Dynamics have 4 robotic cells to drill and rout interchangeable and replaceable access panels for the F-16. G.D. uses another 2 robots for drilling graphite epoxy skins for attachment to the aluminum structure of horizontal and vertical stabilizers. G.D. also have 2 robots to drill and countersink full-size holes in the F-16 wing skins. There are 1400 holes to be drilled which are required to attach the skin to the sub-structure.

McDonnell Douglas, St Louis use a robot to drill attachment holes in F-15 canopies but their approach for this application is different. Four self-feeding air-operated drill units are used, together with an overlay template with tapered lock-on bushings. The robot positions and locks the drill units one at a time on the bushings. When the drill cycle of the 1st unit is over, it moves it to the fifth hole and so on.

3.4 Water-Jet Operations

3.4.1 General

The cutting action of the water-jet cutter is caused by a thin stream of water under tremendous pressure. The operating pressure is upto 60,000 p.s.i. maximum and the nozzle diameter is 0.003 inches minimum. The nozzle concentrates a small diameter stream of high velocity water on the material being processed. This stream is used, as if it is a saw blade, to cut various materials.

The water-jet is used mainly to cut non-metallic materials, such as rubber, fabrics, foam, vinyl, plastics and composites. It's capabilities cover:

- straight line cutting
- contour cutting
- bevel or tapered edges
- irregular edges
- inside/outside configurations
- and cutouts.

3.4.2 Advantages

- Water-jet cutting is a fast, low cost method of cutting/routing non-metallic and composite parts.

- There is no contact between the workpiece and the cutting head, therefore no cutting force to encounter and hence no tool wear to worry about.

- It is a clean process.

- In some cases, it is the only method to cut non-metallics efficiently.

4.4.3 Aerospace Use

Most of the aerospace companies involved in composite manufacturing use the water-jet for cutting composites. Boeing-Vertol division and Grumman Aerospace have developed the use of a robot with the water-jet for composite cutting and others are actively considering robotization of their water-jet operations.

The Canadair water-jet is used for cutting fibre glass and Kevlar components. It can cut components upto 0.25 inch thick and produces burr-free edges.

The water-jet router consists of a tubular frame with an articulated boom which gives five degrees of freedom. The routing head is hand-guided. This arrangement can be used to cut countours in 3-D. However, the water-jet cutting head has been modified at Canadair. The head is fixed above a flat table and only flat components are cut by the water-jet, thus reducing its effective use.

4. OTHER APPLICATIONS

Eleven other processes/areas were analysed for potential application of robotics. The current level of robotic technology and the economics of aerospace production generally hamper the introduction of robotics in these areas, except in individual circumstances. It was also found that there are other effective methods to increase the efficiency of production. But it requires a commitment by management to modernise and introduce newer technologies. The analysis of various areas studied is given, as follows:

4.1 Machine Loading/Unloading/Material Handling

Robots are being used for loading of machine tools with a view to improving productivity and the utilization of machine tools. A robot may not be any faster in loading/unloading a machine than a human being, but its non-stop operation eliminates productivity reducing human factors such as fatigue, loss of concentration, and personal injury.

For successful cost-effective applications, a robot must be kept busy. For maximum return on investment, 3-4 machines should be grouped so that one robot can serve all the machines in the group. Another criterion for efficient robot operation is that the cycle time of components needs to be fairly low.

The most successful applications for robots in machine loading are automatic lathes, gear cutting machines, drilling and stamping presses and operations not performed at Canadair, such as die-casting, forging and foundry work.

Aerospace applications for robots in machine loading seem difficult because:

- The cycle time of machined components is usually high.
- The batch sizes are relatively small.

However, there are applications being developed by some aerospace companies which can be classed as machine tending or loading/unloading. General Dynamics is using an I.B.M. RS-1 robot to deburr tubes and cut them to length. The robot picks up a tube from a feeder tray, touches the face of the chuck (a fixed datum) with one end of the tube. This enables it to know where it has gripped the tube for getting the length right. Then it deburrs one end, reverses the tube and deburrs the other end to the proper length. Boeing Airplane Co. is utilizing a Bendix robot to pick and present a part to a press brake and another one to load/unload a tube bending machine.

The use of robots in the machine tending role in aerospace manufacture, especially in the machine shop is possible and can be effective only if:

- Manufacturing cells are implemented using Group Technology.
- FMS (Flexible Manufacturing System) is implemented which has a prerequisite of DNC.

Robots and conveyors or guided vehicles can be combined to perform the material handling/loading function in a FMS or manufacturing cell. The use of robot in the press shop for feeding blanks to presses can be an effective and demonstrative application, provided the production level is high enough to justify it. For such an application a low technology, low cost robot can be used.

4.2 Deburring

The removal of burrs from metal components is a necessary part of the manufacturing process. When aircraft components are machined, burrs are always created and these burrs can lead to stress concentration.

Burrs and sharp edges are produced during the fabrication process, such as blanking, drilling, routing, milling and other machining operations. A burr-free condition is necessary for compliance with gap requirement on assembly, forming without cracking, prevention of scratches from part to part contact, appearance and satisfactory service life.

The deburring process is a monotonous, dirty, noisy and fatiguing operation.

During the deburring and removal of sharp edges, the finishing process must give a slight radius to reduce stress concentration.

At Canadair, small components less than 30 inches long and 15 inches wide are generally deburred in a vibratory deburring tub with a capacity of 6.5 cubic feet. Parts longer than 30 inches are usually deburred in the vibratory machine of 65 cubic feet capacity, some parts needing fixturing. Parts which are cumbersome, large and unsuitable for vibratory deburring are finished manually. Components in this category are wing skin panels, bulkheads, ribs, spars and frames. These are deburred manually using scrapers and handheld power tools. Some of the drawbacks of the manual task are high cost and inconsistency.

Robot applications for deburring/finishing processes are currently being developed. For example, General Electric is developing a manufacturing cell for finishing (deburring & chamfering) gas turbine engine components. Boeing uses a robot to finish sand the wing of the ALCM.

Specific tasks often require that different tools be used. Therefore, a robot with tool-changing capability is required or the robot will have to present the part to the tool, the latter in most cases being totally impractical.

However, it is felt that most of the manual deburring in Canadair can be eliminated by the introduction of automatic flap brushing, if it can be economically justified. Automatic flap brushing is accomplished by using a buffing machine with buffing wheels "ganged" together and sprayed with an abrasive compound. The development of robots for deburring in Canadair will be costly in terms of capital equipment, programming and effort and must be justified by continuous operation.

4.3 Welding

Welding robots have been used in welding applications for some years now. Earlier robots were continuous path positioning robots. But the new generation of robots has adaptive control capabilities, such as sensing the arc parameters, and the misalignment of the weld joint due to distortion etc.

Spot welding is one of the most extensive applications of robots and is largely used in the automotive industry. Arc welding is another welding process suitable for robotic application due to the stringent requirements for skill and safety. The actual time spent on joining metal is called "arc time". This is approximately 25-30 percent of the total weld operation time. Robotic welding facilitates the improvement in the "Arc time".

Furthermore, use of robots can improve the quality of the welded joint due to consistency of the operation as human operators tend to fatigue as the shift progresses. All these factors lead to the application of robots to the welding process for improved productivity.

The smoke and fumes produced during the welding process are toxic or carcinogenic, hence the process is unhealthy. Noise, radiation and stress are other environmental problems encountered in welding. Furthermore, welding requires skilled personnel. A welder has to be trained and certified making welding an expensive process.

Use of Welding as an assembly/joining process in aerospace manufacture is small compared to other methods. The recent trend in aerospace is the use of:

- composite materials.
- metal to metal bonding.
- integrally machined components.

Therefore it is felt that robot application for welding in Canadair would not be cost effective. The amount of welding we do and the cost of developing a robotic system for in-house use cannot be justified.

Lockheed-Georgia Company has developed a unique application for robotics in their plant. Milling cutters, which have a worn out cutting edge that does not permit regrind, have their cutting edge rebuilt by welding, using a cobalt alloy as a filler. The welding head is attached to a "Cyro" robot. The filler alloy is fed as a wire to the welding head. The cutters are held in a rotary positioner. The welding process, robot and positioner are controlled by a computer. As Canadair has an extensive machine shop this is an attractive proposition.

4.4 Chemical Processing/Heat Treatment

All details in aerospace manufacturing have to go through some form of processing or treatment. These processes are necessary to impart certain qualities to the material needed in subsequent operations or in service. For example, cleanliness, corrosion resistance, paint adhesion, strength or hardness.

Robots have been used in the heat treatment process for loading and unloading. However, the process has to be continuous and workload large enough to keep the robot busy. Furthermore, aerospace components that are heat treated are usually large or awkward in shape or the quantities are small and cycle times are high.

All aerospace metallic components have to go through some sort of chemical processing, therefore the volume is considerably high. However, it is felt that automation using programmable controllers and/or mini-computer would be more effective than robots.

Lockheed-Georgia Company have installed a computer based Automated Paint and Process Line (APPL) to finish process and paint parts for aircarft. Parts are loaded on racks, which are identified by a numbering system dependant upon the finishing process. These racks are automatically sequenced from one tank to another according to hte precessing specification by a computer controlled crane. The processed parts are finally painted by robots.

The advantages of such a system lies in the consistency of processing, improved productivity and possibly unmanned 2nd/3rd shift operation. Furthermore, there is less exposure to the unpleasant chemical environment for the operators.

4.5 Sheet Metal Operations

The Manufacture of sheet metal components basically has not changed in the last 40 years. Rectangular blanks suitable for the template are guillotined from a stock sheet. These are transported from the guillotine to the drill where holes are drilled through the stack using the template. Then the stack and template are transferred to the routing machine. After setting up, the router center follows the template to cut the sheet metal stack. This method of producing flat sheet metal components or blanks prior to forming has essentially remained the same over the years.

Robots are being used for routing in the Aerospace industry. General Dynamics, Fort-Worth is using a robotic cell to drill holes and trim the periphery of certain F-16 skin panels after forming. However, for producing flat parts and blanks a CNC router is most efficient, because:

- It eliminates the templates
- It combines 3 operations into 1, hence reduces set-ups.
- It is faster than the human operator.
- It saves material because a number of parts can be nested.
- It reduces lead times and work in progress.

Although the advantages are obvious it is ironic that for the present the use of robot for sheet metal operations does not appear to be cost effective. However, the use of a robot with the CNC drill and routing machine for a flat component/blank producing cell as an island of automation can be envisaged. The robot can transfer cut blanks from the router to a deburring machine while another robot, with sensory (vision) feedback can identify the blank as it comes off the deburring machine and mark the part number with a laser or ink jet.

4.6 Electrical Harness Making

The manufacture of an electrical harness is one of the most labour intensive processes in aerospace production. It has remained a long laborious process unchanged over the last 40 years. The aerospace industry has a large variety of harness configurations, connectors and wire types. They are also subject to much design change in the early production phase.

The fabrication of a harness can be broken down into the following broad steps:

- Fabrication of a harness board from the drawing/mock-up.
- Marking, stripping and terminating each wire.
- Laying up the wires on the harness board.
- Tying wires into bundles.
- Apply sleeving
- Inserting Wires into end connectors.

Although there are machines which can automatically mark, strip and terminate a wire, no integrated machine or system exists which can perform all the steps in harness manufacture.

However Lansing Bagnall, in the UK, is using a robot for the manufacture of harnesses without a permanent harness board. The robot is mounted above a nylon grid-matrix, into which locating pins are inserted by the robot. These pins are used for locating the wires in the harness. Wires are fed through a magazine in sequence and cut to length. The robot routes each wire along the path around the locating pins. At he end of the cycle, the robot tapes the bundle ready for further operation. Boeing's C.C.H.M. (Computer Controlled Harness Marker) is similar in operation, except that instead of a robot an X-Y machine is used with a special head.

These X-Y machines cannot be cost effective unless there is a large production run, which is not probable in the aerospace industry. However, the use of robot and the automatic board building system (such as Lansing-Bagnall of UK) looks promising because of the flexibility of robots. Unimation Inc. is developing a harness fabrication centre together with Hughes Aircraft. This computer controlled, automated system for harness manufacture will centre around a Puma 560 robot. The system will include automated equipment for marking, stripping, routing, terminating, tying and inserting wires. The system will have off-line programming capabilities.

McDonnell Douglas Corp. has tested and recently introduced into production a new application for robots in wire harness assembly. it is for inserting sealant pins in electrical connectors using an overhead gantry type robot built by Nova Robotics, Inc.

The robot controller is linked to a DEC 11/34 computer through a RS232 interface and communications protocols developed by Nova. The computer is also linked to the company CAD data base. The DEC machine automatically generates robot programmes using the CAD data base.

4.7 Composites Manufacturing

The use of graphite/epoxy in aerospace is increasing at a tremendous pace. The use of composites has risen from 5 per cent by weight in early seventies to 10-11 per cent on F-18, around 23 per cent on the AV-8B and probably 50-55 per cent on future aircraft.

The major thrust towards composites is in the military aircraft field because of the primary goal of improved performance. By comparison the civil aircraft industry may seem conservative in the use of composites e.g. 3 per cent by weight on Boeing 767. However the introduction of composites on new aircraft is getting more and more common, e.g. the Learfan, which has a fuselage completely made of composite materials. It is predicted that beyond the year 2000 up to 65 per cent of the weight of a commercial jet may comprise composites.

Composites manufacturing is not only labor intensive and time consuming but intensive quality requirements drive up the costs. There are six basic steps in the manufacture of composites.

- The preimpregnated composite material is spread onto a cutting table.
- The material is cut to shape.
- Each piece is removed from the table and stacked, in sequence, with specific fibre orientation on the tool.
- For critical thicknesses stage debulking is required.
- The part is vaccum bagged and cured.
- The part is debagged and removed from the tool.
- The part is trimmed to the final shape.

These operations can be automated with the use of robotics. The most suitable operation for a robot would be the laminate build-up, (i.e.) the stacking of composite layers and final trimming of the part after curing. The cutting of the prepreg to shape can be efficiently done by a reciprocating knife or laser. The NC controlled machines for these are available on the market now and are in use by other aerospace manufacturers.

Long term composite materials development at Canadair call for the provision of an automated production facility. However, in the short term, the use of robotics in composite manufacture can be undertaken, only in a laboratory environment provided that the funds are available.

Northrop is developing a computer controlled robotic work cell under U.S.A.F. funding, where composite components will be manufactured without human intervention.

The work cell is designed around a Gerber reciprocating knife, the broadgoods spreader (used in the clothing industry) and a robot. The composite plies are cut on the NC operated reciprocating knife cutter, which is mounted on a gantry across the cutting surface. The cut plies are

stacked automatically and transferred to the assembly area by electrified monorails mounted in the ceiling. The cut plies are laid automatically by a "Cincinnati-Milacron" robot. The robot is equipped with a foam faced vacuum head to pick, transfer and lay-up the plies. The robot also has a visual sensor (a TV camera) with which it can recognize the shape and orientation of the cut ply.

Before the start of the next cutting cycle, the table is automatically cleaned of any leftover scrap material and double checked by a video camera mounted overhead.

4.8 Assembly

Assembly of an aircraft is far more complex than that of an automobile, or any other mass produced item because of the peculiar characteristics of aerospace components. These components must be lightweight, yet sufficiently rigid, flexible and fail safe. Some parts have to be large, yet have close tolerances. Furthermore, thousands of a variety of such parts are required to make the composite whole.

This makes the assembly operation in the aerospace industry highly labour intensive. The most common assembly operation in aircraft manufacture is in the drilling of holes, application of the sealant or paint primer in the hole, inserting a fastener and installing it. A modern aircraft has thousands of fasteners, therefore the assembly operation takes a major portion of the labour cost involved in its manufacture.

A robot for assembly must be designed to pick parts from a storage and fasten them together into an assembly. This will require a relatively articulate robot with

- a high level of sensory feedback - This will include tactile sensing and vision. Tactile sensing to sense misalignment, perpendicularity assembly force requirements etc., and Vision for part recognition and orientation.

- a high degree of control capability - This will include multi-axes control with off-line programming preferably with a high level APT-like language.

- complex tooling and parts feeders - because of the large variety of assemblies with small batch sizes.

Application of robots in assembly is still in the research stage, although Lockheed has developed a robotic cell in combination with a drivmatic machine to manufacture small assemblies such as cargo floor web and flat sheet metal panels. Most of the research is focussed on vision recognition and force feedback systems to provide better adaptability.

Boeing is using a Puma 560 robot to bond studs on the interior panels of the 757 and 767 models. This is a simple but effective application and requires a relatively low technology robot. It has been justified because of the large quantities of interior panels Boeing expect to produce. Some aerospace companies are investigating the use of robotic cells in the

assembly of fuselage frames, panels and wing skins. However, it is felt that the implementation of such cells will take at least 5-6 years.

For the purpose of this study the assembly process cannot be considered as a demonstrative application because of the high level of technological effort required for the uncertainty of return on investment. It could be a development task if a robotics lab was established.

4.9 Drivmatic Operations

Because the assembly process in the manufacture of an aircraft consumes a major portion of the total labour cost for an aircraft, it must be the focus of automation and productivity improvement endeavors. However, slow production rate and small batches dictate the degree of automation that is feasible, or even possible.

Installation of fasteners has a great potential for automation in aircraft production. A certain degree of automation has already been achieved in this area by the use of the "Drivmatic" drilling and rivetting machine. Components, with a large number of fasteners to be installed in rows, very close together qualify to be put on the drivmatic machine for assembly. Usually these are skin panels.

The rivet positions are masked as dots on the skin surface. The operator positions the assembly under the machine head. Then the machine automatically drills the hole, inserts the fastener and installs it (upsets the rivet).

The operator has a demanding and time consuming job, although labour saving devices are employed such as cranes and balanced jigs. The operator must visually spot each rivet position and locate the assembly prior to drilling each hole. Thus the correct location of the fasteners depends on the operators skill and concentration. Fatigue and boredom late in the shift, which is normal, could create some quality problems.

There are new Computer Numerically Controlled (CNC) work positioners on the market, which position the part automatically under the machine head. However, this equipment is expensive and complex to program. Hence it is very difficult to justify.

After several years work in the laboratory, Lockheed Georgia has developed a robotic workcell to produce sub-assemblies, such as cargo floor webs, wing bulkheeds etc. The cell consists of a robot - a Cincinnati-Milacron T3 and an automatic drill-riveter. The operator loosely assembles the parts in a light mini-jig. The jig is placed on a specially designed table. The robot picks it up from the table and presents it to the Drivmatic machine. The machine then installs the fastener. The robot automatically moves the assembly to the next position and the machine installs the fastener in that position. This cycle is repeated until all the fasteners are installed according to the program. The robot will then return the jig and assembly to the holding table and pick up the next assembly.

Lockheed California has an experimental program to use visual sensory feedback method for automatic fastening of aircraft structures. This experimental cell contains a robot, a vision system and a drivmatic, all

under their own computer control. All of these components are controlled by a cell supervisory computer. Each of the individual cell components have specially developed and dedicated software.

The computer vision is used for determining the position and orientation of parts and/or part features, for recognition of parts and for positioning. The configuration data of a part is accessed by the cell computer from the engineering data base. In the drivmatic application the vision system can sense the edge distance and check whether it is within tolerance or not.

Undertaking of this application in Canadair will require development of special tooling for work handling, end-of-arm tooling and a great deal of programming effort. Canadair rate of production, now and in the near future, precludes consideration of this application, unless a Robotic laboratory is established.

4.10 Extrusion Finishing

A considerable number of parts in an aircraft are manufactured from extruded sections. Some are straight, some have to be formed on the stretch forming machine and some contain joggles. Almost all have holes whether drilled or machined and have legs or flanges machined to some shape.

The "Sundstrand Parts Maker" is specifically designed to machine extrusions and bar stock. It has the capability, under NC control, to produce complete parts from extruded sections or bars in one set-up. But this machine can only produce straight parts. If the part is formed or has joggles then they cannot be put on this machine. Furthermore, this machine is expensive and difficult to justify unless there is a large production run.
Lockheed-Georgia have developed and will be putting into production a robotic application to finish machine components made from extruded sections. The robot machines cutouts, shapes flanges, drills holes and finishes the ends of a component after stretch forming. However, this requires hard tooling, which already exists for the manual method.

Finishing (i.e. drilling and routing) of extruded sections, without the use of hard tooling, could be a potential application for robotics, if the machining technology (i.e. drilling & routing) with robots is established and off-line programming is possible.

This is another process that must be considered for development in a robotics lab.

4.11 Sealing

Sealants are generally used in aircraft manufacture to attain an airtight joint. One of the uses of sealants is on the wings to seal the integral fuel tanks or fuel cell cavities. For such application sealant bead is applied with an air powered sealant dispenser. In some cases, the sealant has to be applied in a restricted area, e.g. CP140 wings. This application could be considered to be similar to the welding process, as far as robotics is concerned, except that the accuracy requirements are not as severe as in welding.

Another use of sealants is in faying surface sealing. When assembling two parts, the sealant is applied on the mating surfaces, just prior to assembly by brush or roller. Then the fasteners are installed. However, all machining operations are to be performed before the application of the sealant.

Use of robots for such applications cannot be considered at this stage because such a robot will have to be versatile and intelligent enough to drill, deburr, seal and assemble the parts. For integral fuel tank sealing, the robot will need visual feedback, which is beyond the scope of this task. Furthermore, it is felt that the volume of production does not justify the use of robots for sealing. But this again could be a potential area for laboratory development.

4.12 Misc. Application

Robots have been considered and will be used in the non destructive inspection (NDI) of aircraft components. The U.S. Air Force is acquiring a robotic system to inspect a fighter-size aircraft with X-ray and neutron radiography. The benefit of this system is that inspection operation is performed on the entire aircraft eliminating disassembly of aircraft as required by the current process.

GCA is developing a gantry type robot for prepping and painting an entire aircraft. This robot will be able to clean, laser-strip the paint, polish and paint.

The U.S. Navy has developed a robotic deriveting system to remove rivets from an aircraft. The robot locates rivets using a vision system, drills rivet heads, punches out the shanks and inspects the rivet hole for corrosion and cracks using an eddy current probe.

Boeing Vertol has developed a robotic system to manufacture composite honeycomb core. The system consists of a Unimation S6000 robot, a horizontal bandsaw and several cutting tools of unique designs. The system machines honeycomb core components of highly irregular shape from a large block of core.

5. DISCUSSION

There are two major aspects to the study of robotics in aerospace, technical feasibility and economic viability.

The major points in technical assessment are the accuracy and ease of operation. The introduction of robots in the aerospace sector was slow because of the inherent inaccuracy and difficulty in programming. The accuracy of earlier generation of robots did not meet the aerospace industry requirements. The low accuracy in these robots was mainly due to the use of hydraulic drives, weighty design needs, high inertia of moving parts and associated control requirements. However, recent advances, such as electric drives, improved motors and better load carrying capacity will increase the accuracy of a newer generation of robots.

All the earlier generation of robots were programmed by either lead-through method or by teach pendants. These methods are cumbersome and time consuming. Considerable productive time of the robot is taken up for programming. However, newer programming languages and systems, such as Unimation's VAL II take programming a step further towards off-line. True off-line programming, similar to NC machines, is at least 5 years away.

Despite these shortcomings of the earlier robots, the aerospace industry in North America started using robots, first in a laboratory and then on the production floor. This was possible because the low accuracy of the robot was compensated by clever design of the end-of-arm tooling. However, the newer generation of robots have improved in accuracy and so are being considered for more & more applications.

As far as the economics is concerned, Aerospace companies using robotics have found that improvement in productivity due to robotics in production can be up to 400%. Northrop have found that use of a robot in composite lay-up has reduced the material transfer time by 66%. General Dynamics have found that by using a robotic cell the production efficiency has improved by 4 times over an equivalent manual operation. McDonnell Douglas have observed similar improvements in their canopy drilling operation.

This clearly shows that robots can be utilized in aerospace manufacturing and their use will keep on growing. More and more applications are being considered and studied. The variety of applications in the U.S. aerospace industry indicates the great opportunity we have for taking the first step towards establishing a Canadian presence in aerospace robotics.

Traditionally, justification of any investment is based principally on direct labour savings, material savings and increased productivity. These justifications do not show the hidden benefits such as improvement in work environment, reduced inventory, better scheduling and improved quality. The product quality can be improved when it is dependant on an operator's skill. Aerospace production, although High-tech, is labour intensive. The quality improvements due to robotics are generally due to the high repeatability and consistancy of a robot in performing a task in comparison to a human operator. Improved scheduling and inventory control can be also be achieved if robotic cells are implemented for a family of parts utilizing Group Technology techniques.

All the aerospace companies engaged in robotics have set up their own laboratories. These are necessary, not only to build up the required skills because there is no available pool of people with robotics experience, but also to disseminate the technology to the production floor and the maintenance areas. It also helps to reduce the degree of dependance on outside people with robotics expertise.

The lack of in-house expertise may be a factor of concern to a company entering into the robotics field, but we must remember that all companies have had this problem. One needs to set up a team, with members from such disciplines as manufacturing engineering, design, computer science and electrical/electronic engineering.

The robot itself is only a small part of a total robotics system. The various components of the robotics system, such as the end effectors, safety sensors or cell control system can best be integrated in the laboratory prior to the implementation on the production floor. Moreover, other related "enabling technologies" such as machine vision, various types of sensors, adoptive control and off-line programming are still in the development stage. The utilization of these is inevitable in the evolution of robotics. The integration of these technologies has to be done in house and a robotic laboratory is essential or this purpose.

Most of the larger U.S. aerospace companies have been active in robotics since 1977. This is due to the involvement of government agencies such as USAF Materials Laboratory and Defence Advanced Research Projects Agency (DARPA). These agencies support projects for near-term applications as well as R & D work to establish a technology base for the future. The intention is to establish these technologies in actual aerospace manufacturing facilities to increase productivity and quality and to reduce costs. Without such heavy government support, the development of robotics in aerospace would have been very much slower.

Robotics is a relatively new technology. And like any other business or technology, there is a learning curve which must be traversed. Other aerospace companies are demonstrating that we must acquire this technology to be competitive and perhaps, to survive. Those companies or industries which wait too long for the opportune moment might find it almost impossible to catch up with competitors. Although the economic justification for robotics is difficult in the present situation, this is the time to modernise and develop new technologies.

There are a number of potential robotic applications in Canadair that should be initiated. The applications are drilling, routing/trimming of composites by water-jet. These are selected because of their extensive use in the fabrication of aerospace components. Because of complex nature of aerospace components, the applications selected will require a high technology robot - a continuous path with minimum 6 axes preferably electrically driven. The cost of such a robot will be upto $120,000. Most of the robotics experts/consultants and users quote the cost of development of an "application" between 2½ to 5 times the cost of the robot and development time between 1 to 3 years.

6. CONCLUSIONS

We have found that the most promising areas for robotic application in aerospace manufacturing are drilling and routing/water-jet cutting. These are selected for follow-on evaluation because thousands of holes are drilled for the fasteners required in aircraft assembly and most of the parts require some form of cutting or trimming either prior to or after assembly. Furthermore, development of these processes will provide an opportunity to apply robotics to other applications.

The use of robots in manufacturing is growing rapidly. A conservative estimate puts the growth at doubling every five years. The leaders in industry are the automobile industry and the electrical machinery manufacturing industry. Robotic application in the aerospace industry has lagged behind other industries, largely due to its peculiar environment and demands, but is now moving rapidly ahead. The introduction of the new generation of robots with electrical drive, higher accuracies and higher load carrying capacities has given the aerospace industry new impetus.

This is a new technology that must be acquired. We must go through the learning process and surmount the learning curve before it can be used effectively. The new skills and experience required for this technology will be best acquired by establishing an in-house robotics laboratory.

The development of robotics in the Canadian aerospace industry will require government support and development funding. If the airframe manufacturing industry in Canada is to remain with the leaders in the world aerospace industry, we have to establish a Canadian presence in the use of robotics in the specialised high technology areas.

7. RECOMMENDATIONS

In order to further explore and develop the necessary skills, knowledge and the technology base for robotics in the Canadian airframe manufacturing Industry, it is recommended that the follow-on be initiated at the earliest moment.

The work statement can be described as follows:

7.1 Select, purchase and install a robot, suitable for Drill/Rout/Waterjet application.

7.2 Test the robot for its capabilities and limitations e.g. repeatability & accuracy at various points in its work envelope.

7.3 From a concept and design End-of-Arm Tooling for these applications.

7.4 Design a work holding fixture.

7.5 Develop the prototype End-of-Arm Tooling and work holding fixture.

7.6 Evaluate the operation of the robot with the End-of-Arm Tooling in a simulated production situation.

7.7 The approximate cost of the follow-on is assessed at $300,000 (1983 dollars) with $120,000 being the cost of the robot. The project would require approximately 2 years to complete.

The integration into a work cell and possible DNC type link with the design data base will be undertaken at a later stage.

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